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# MAST FLIGHT SYSTEM OPERATIONS

M. LARRY BRUMFIELD
NASA LANGLEY RESEARCH CENTER

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## MAST FLIGHT EXPERIMENT

An artist's concept of the MAST Flight Experiment is shown in Figure 1. The Mast Flight System is a 60 meter long deployable truss structure. Detailed descriptions of the system have been given in previous papers at this conference and will not be repeated here. MAST will be mounted on a STEP/SPACELAB pallet and integrated into the Space Shuttle payload bay for orbital flight testing. It will occupy one-quarter of the payload bay space, but will require more than the standard one-quarter allocation of orbiter power.

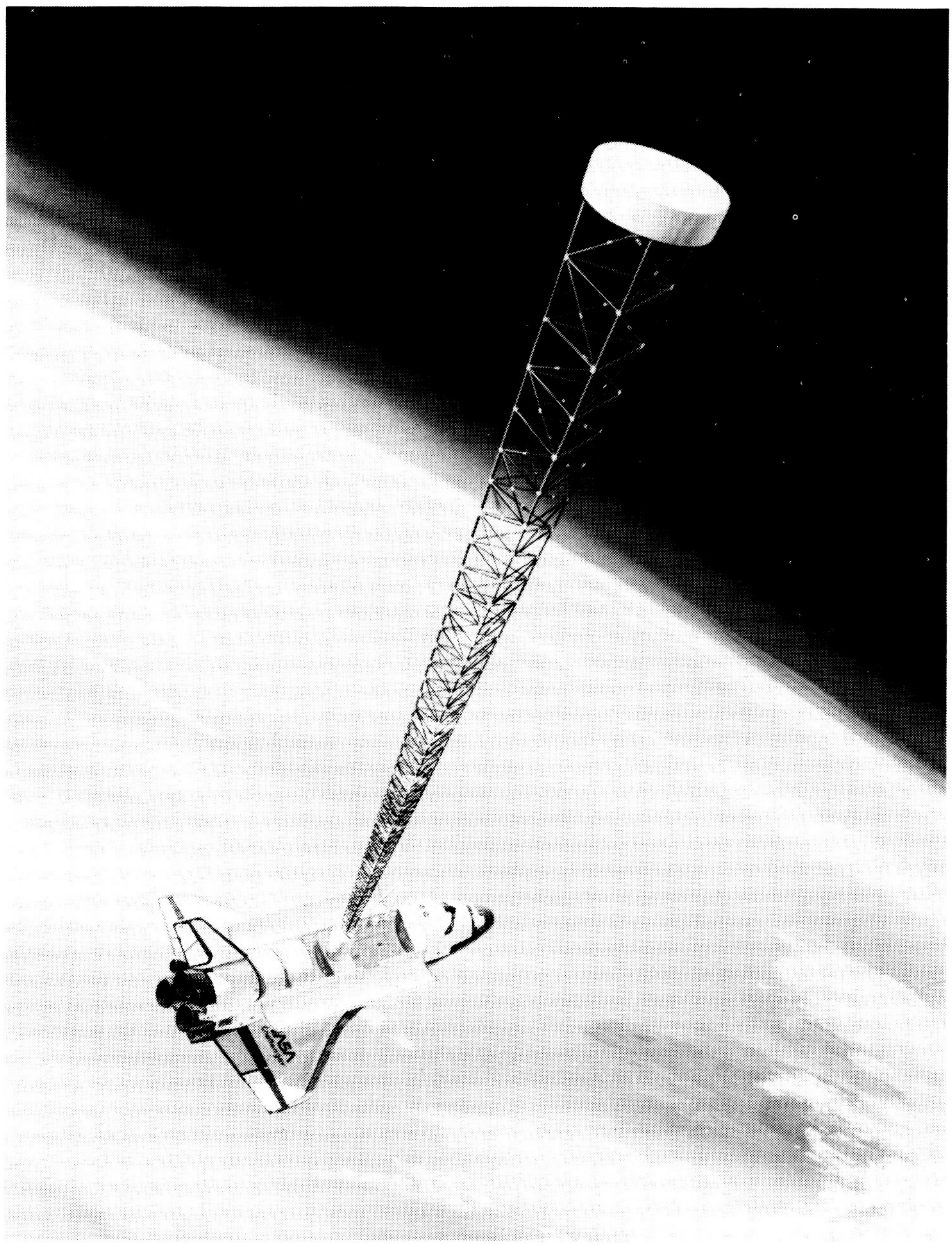


Figure 1

## MAST 1 FLIGHT TEST OBJECTIVES

The first flight of MAST will emphasize structural dynamics and will be focused on determining the structural characteristics from the measured dynamic responses to controlled excitations. A major thrust will be evaluating state-of-the-art system identification techniques. In addition, the latest actuator and sensor technology will be evaluated as it can be applied to in-space testing of large, lightweight structures.

**MAST I**

**EMPHASIZES DYNAMIC CHARACTERIZATION OF THE BEAM TRUSS**

1. **TO DETERMINE THE STRUCTURAL/MODAL CHARACTERISTICS OF THE MAST FLIGHT BEAM**
2. **TO EVALUATE SYSTEM IDENTIFICATION AND STATE ESTIMATION ALGORITHMS ON COMPLEX, LIGHTWEIGHT STRUCTURES IN SPACE ENVIRONMENT.**
3. **TO EVALUATE ACTUATOR/SENSOR/MEASUREMENT TECHNIQUES APPLICABLE TO LIGHTWEIGHT, LOW-FREQUENCY STRUCTURES WITH LOW DEFLECTION/DETECTION TOLERANCES.**
4. **TO PERFORM ACTIVE DAMPING OF THE BEAM USING REAL-TIME DATA FEEDBACK.**

Figure 2

## MAST 2 FLIGHT TEST OBJECTIVES

The second flight of MAST will emphasize flexible body controls experiments. A major thrust will be the use of both collocated and distributed actuators and sensors. Both the open-loop and closed-loop stability will be evaluated very carefully. Of particular interest will be the level of maturity of the various control law design methodologies and whether they provide sufficiently robust control mechanizations for large, lightweight, flexible structures. The second flight will provide the vehicle for implementing the selected guest investigator experiments. (The guest investigator program will be discussed by Mr. Anthony Fontana in the next paper.)

The remainder of this paper will focus on the flight operations planning associated with the first flight of MAST.

**MAST 2**

**EMPHASIZES FLEXIBLE BODY CONTROLS EXPERIMENTS**

1. **TO DEMONSTRATE CONTROL LAWS USING COLLOCATED ACTUATORS AND SENSORS.**

2. **TO DEMONSTRATE CONTROL LAWS USING DISTRIBUTED SENSORS AND ACTUATORS.**

3. **TO DEMONSTRATE BOTH OPEN-LOOP AND CLOSED-LOOP STABILITY.**

4. **TO PROVIDE A TEST STRUCTURE FOR IMPLEMENTATION OF GUEST INVESTIGATOR EXPERIMENTS.**

Figure 3

## THE TYPICAL FLIGHT PLANNING PROCESS

The Marshall Space Flight Center(MSFC) provides the Mission Manager for the MAST Flight Experiment. This Mission Manager acts as the interface or representative between the experiment team at Langley Research Center(LaRC) and the flight planning group at Johnson Space Center(JSC). Personnel at the Johnson Space Center prepare all the flight procedures, crew checklists, flight timelines, etc., necessary to support the actual flight experiment on the orbiter. The physical integration and mounting of the flight hardware is done by personnel at the Kennedy Space Center(KSC).

The key to this whole process is an Integrated Payload Requirements Document(IPRD). To develop this document, the Mission Manager must pull in a number of different requirement documents, beginning with the Experiment Requirements Document(ERD) that is unique to the MAST experiment and is prepared at LaRC. There are a myriad of existing requirements documents that are levied on any orbiter flight experiment. The primary ones are: NHB 1700.7A - Safety Policy and Requirements for Payloads Using the Space Transportation System (STS), JSC 07700 VOLUME XIV - Space Shuttle System Payload Accommodations, SLP/2104 - Spacelab Payload Accommodation Handbook, and JA 447 - Mission Requirements on Facilities/Instruments/Experiments for Space Transportation System (STS) Attached Payloads.

The Integrated Payload Requirements Document(IPRD) develops a specific set of requirements to guide the STS integration and the flight operations, specifies a set of design and performance requirements for any unique interface hardware or software needed to accommodate the experiment system, and establishes the required verification the experimenter must perform to demonstrate that all experiment systems adequately meet all orbiter/carrier requirements. Out of the IPRD comes an Instrument Interface Agreement that governs the design and development of the interface between the experiment system and the STEP/Spacelab pallet, and an Operations and Integrating Agreement that guides the integration of the experiment/carrier into the orbiter and the orbital experiment operations.

A detailed Payload Integration Plan is developed at JSC for use in the actual physical integration at KSC and in the final flight planning. The actual crew documents come out of this flight planning process. There are many design reviews, planning meetings, flight operations reviews, flight readiness reviews, safety reviews, etc., that cannot be illustrated here, but the experiment design certification process will be described further in the next figure.

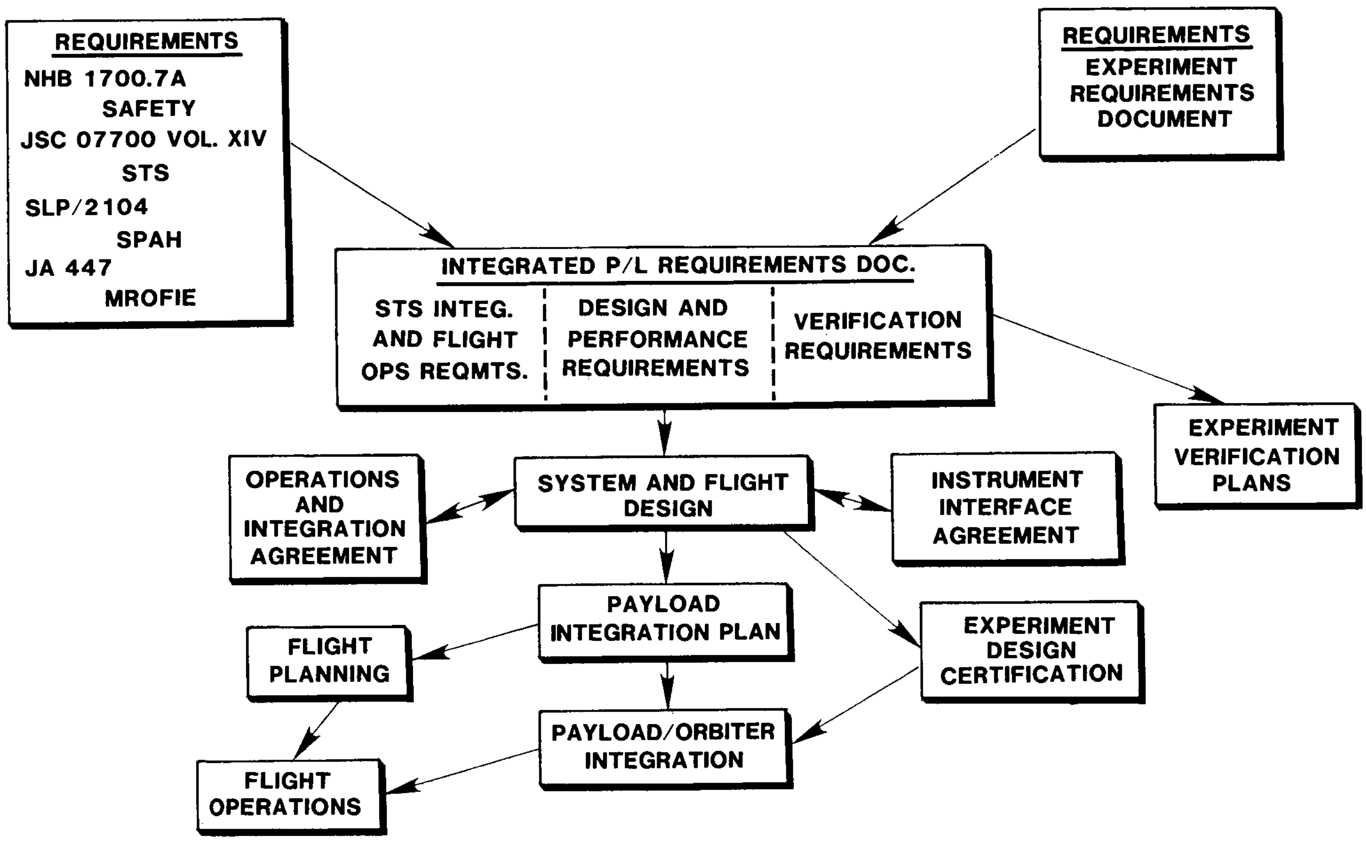

REQUIREMENTS
NHB 1700.7A
SAFETY
JSC 07700 VOL. XIV
STS
SLP/2104
SPAH
JA 447
MROFIE
REQUIREMENTS
EXPERIMENT REQUIREMENTS DOCUMENT
INTEGRATED P/L REQUIREMENTS DOC.
STS INTEG. AND FLIGHT OPS REQMTS.
DESIGN AND PERFORMANCE REQUIREMENTS
VERIFICATION REQUIREMENTS
EXPERIMENT VERIFICATION PLANS
OPERATIONS AND INTEGRATION AGREEMENT
SYSTEM AND FLIGHT DESIGN
INSTRUMENT INTERFACE AGREEMENT
PAYLOAD INTEGRATION PLAN
FLIGHT PLANNING
EXPERIMENT DESIGN CERTIFICATION
PAYLOAD/ORBITER INTEGRATION
FLIGHT OPERATIONS

Figure 4

## CERTIFICATION

Since the primary emphasis in certification is safety, it will be referred to as the safety process. There are a number of requirements that must be met in the safety process, but the key governing documents are as follows: NHB 1700.7A (which has already been named), JSC 13830 - Implementation Procedure for STS Payloads System Safety Requirements, and JA-012B - Spacelab Project Office Payload Safety Implementation Approach. The process is coordinated by the MSFC Mission Manager in cooperation with counterparts at JSC and KSC. First, the exprimenter must prepare a set of hazard reports that identifies and describes each hazard associated with the flight hardware and experiment process. The initial preparation is soon after the experiment conceptual design review and is submitted prior to scheduling a Phase 0 safety review. Hazard reports must be maintained current and updated in keeping with the phased safety reviews so that they always reflect the current experiment configuration.
A set of safety verification plans must be developed jointly between the experimenter and the Mission Manager that specify the process by which the experimenter/integrator will verify that the payload meets all safety requirements. The hazard verification plans must also be updated and eventually contain results obtained when implementing the various test/verification procedures in the plans. Both hazard reports and safety verification plans/results become part of the safety compliance data packages submitted to support the phased safety reviews.
The Mission Manager reviews all experimenter prepared documents for completeness and accuracy and assembles the official safety data packages to the appropriate safety review panels. This is an iterative process that is related to the overall experiment development and integration process. It is geared toward assuring that the payload is certified safe to fly at some time just prior to the final flight readiness review.

# SAFETY PROCESSS

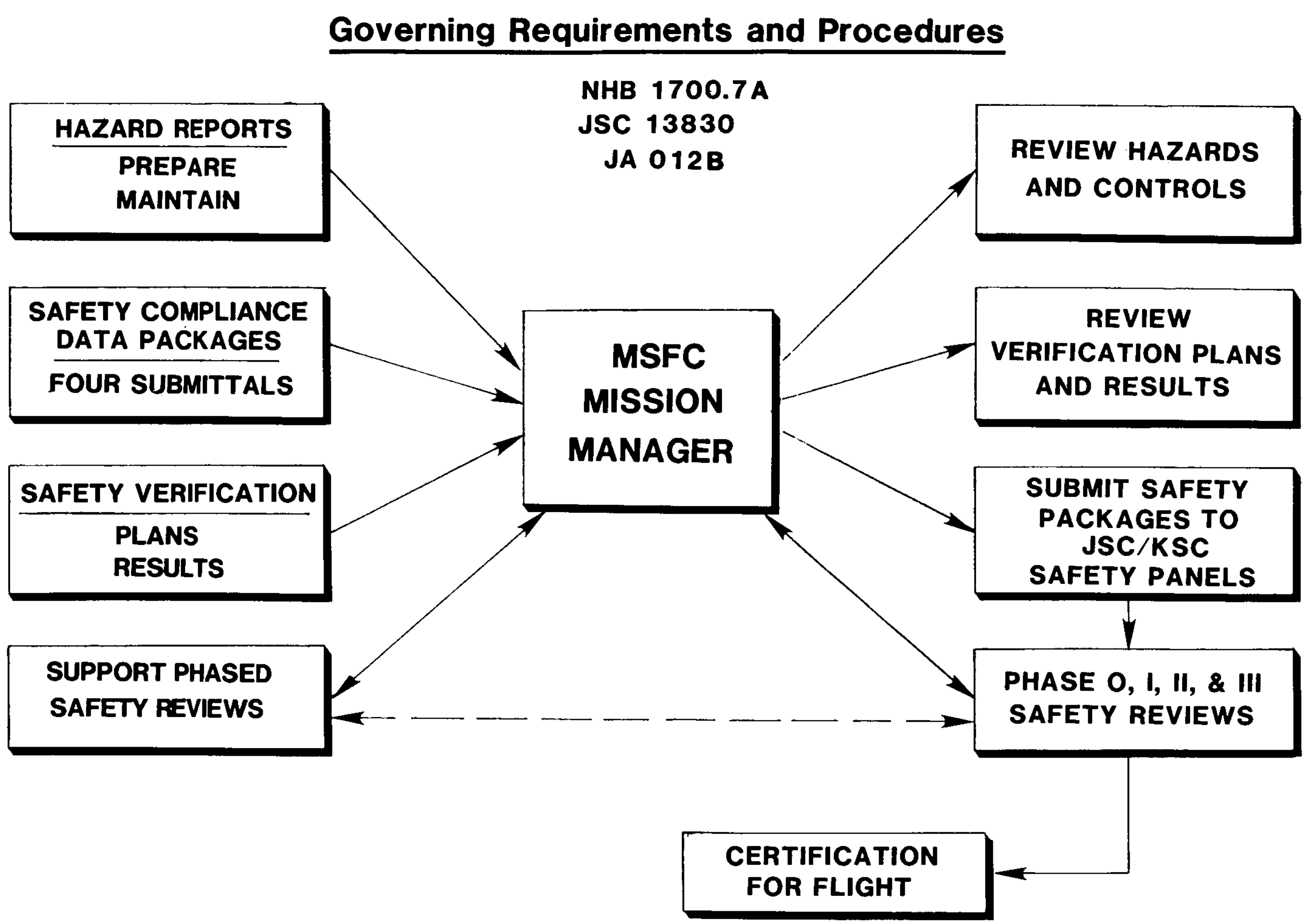



Figure 5

## INTEGRATION MILESTONES

The major milestones in the experiment development and integration process are shown in Figure 6. The reader is advised that this is not the official contract schedule for development of the MAST Flight System(MFS). Rather, this is an attempt to fit a set of integration milestones into the time bounded by initiation of the program and the best estimate of the launch date. Currently, the MAST-1 flight test is scheduled for a May 9, 1991 launch. A conceptual design review(CoDR) has been held for the truss beam, and a preliminary design review(PDR) for the MAST Flight System is anticipated about the end of March 1987. Critical design review(CDR) will follow PDR by approximately 6 to 7 months. After the MAST Flight System is delivered to LaRC, there will be a period of ground testing to refine the modeling and predictions as well as validation of flight software. The MFS must then be recertified for flight before delivery to KSC.

The process of integrating the MFS with the Space Shuttle has already begun with dicussions of preliminary requirements and preparation of the initial reports identifying potential safety hazards. This is leading to a Phase Zero safety review near the end of this year. An integration requirements review(IRR) will follow the experiment PDR by some 6 to 8 weeks and will result in documentation of all the requirements that must be met in the process of integrating the MFS with the carrier pallet and then with the Space Shuttle orbiter. The actual interface (both hardware and software) between the experiment and the orbiter now starts through a design and verification process. There will be an integration preliminary design review(IPRD) and critical design review(ICDR) which will result in the necessary baseline documents and configuration control documents.

After the IPDR, the flight planning activity begins in earnest at JSC. This is an iterative process that involves the continual participation of appropriate MSFC and LaRC personnel. Numerous flight planning documents must be prepared and reviewed to establish and validate precise operational procedures for the flight. The various working groups and reviews at JSC are too numerous to detail in the figure. Some key reviews are of the MAST proposed ground operations(GOR) and flight operations(FOR) to ensure that those JSC persons that develop the details for the orbital operations thoroughly understand the experiment operations. A detailed integration readiness review(IRR) is held just before the MFS is shipped to KSC. A Space Shuttle flight operations review(SSFOR) is held to ensure that all experiment procedures, timelines, crew checklists, etc., are ready for the flight. The process of safety certification has already been described and only the phased safety reviews are shown here. The last thing is the flight readiness review(FRR) just before flight.

# MAJOR MILESTONES FOR MAST-1 INTEGRATION

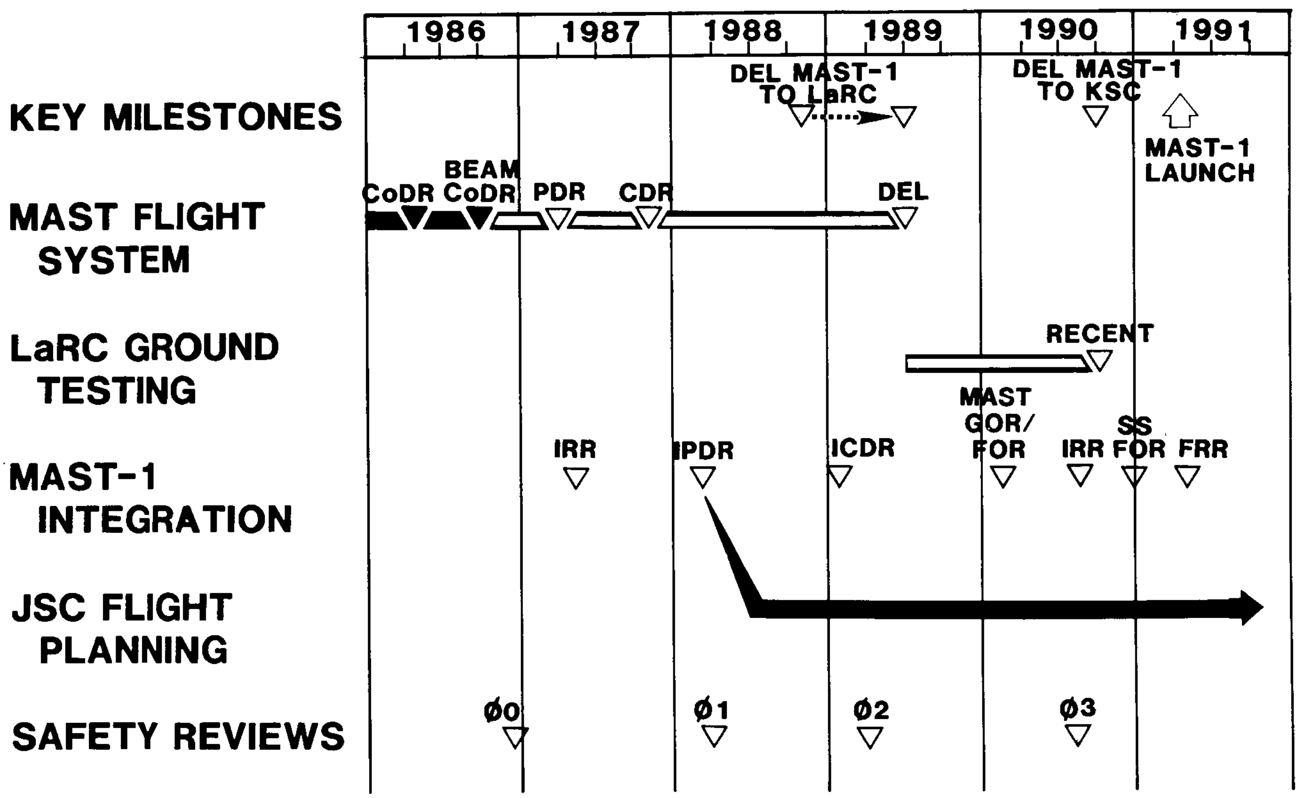
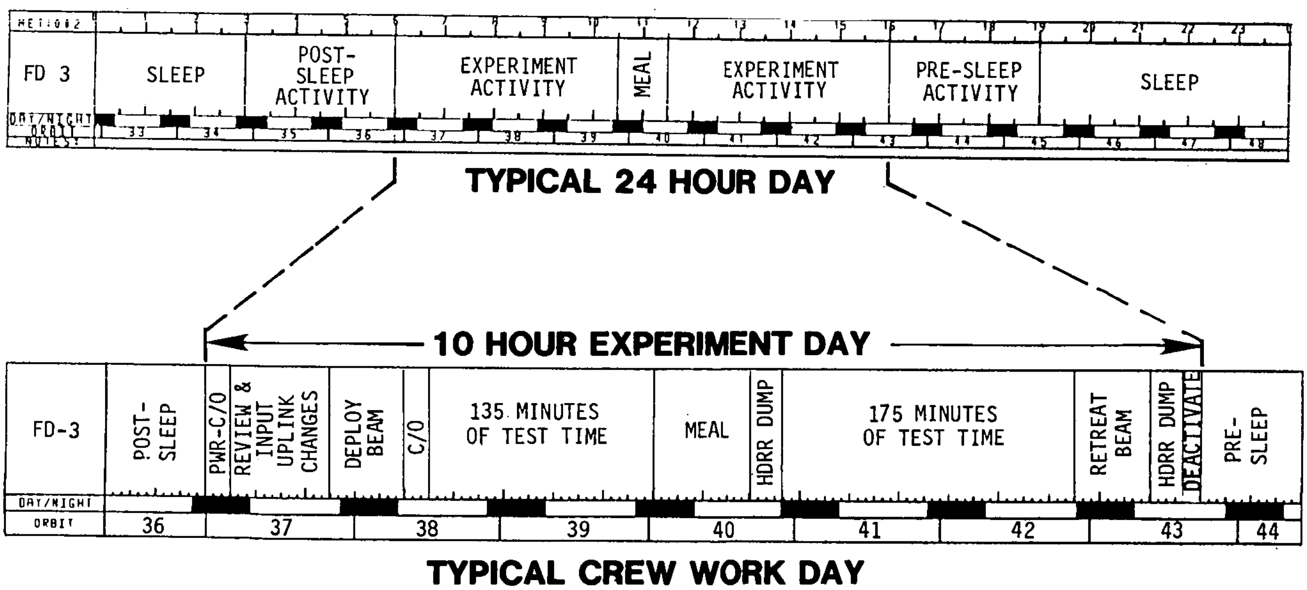



Figure 6

TYPICAL ORBITAL PLANNING

A typical day's activity is shown in Figure 7. Times shown are best estimates as of now and must be refined and fine-tuned as the experiment process is more specifically defined. This is representative of what must go into planning a day of orbital testing. Only MAST test activity is shown when in reality there are other experiments that will have activity that must be fitted into the final timeline. Every crew activity must be planned and shown in the detailed timeline as well as written into the crew checklist. (The crew checklist is a companion document to the timeline and lists the actual steps the crew implements in the performance of the orbital experiment.) This is a continuing process in which the JSC integration personnel interact with all experimenters to develop a flight timeline that accomplishes as many of the flight test objectives as possible for all experimenters on the flight. The working goal is to have the final timeline established about six months before launch.

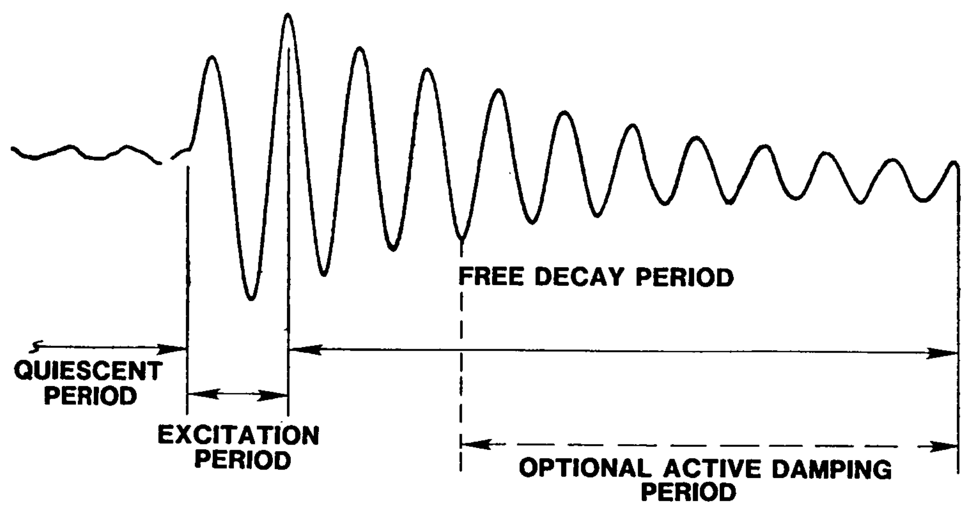



- **NEED 3 TO 4 DAYS DEDICATED TO MAST TESTING**
- **TIMES FOR INDIVIDUAL TESTS VARY ALLOWING FLEXIBILITY IN FINE-TUNING A SPECIFIC TIMELINE**
- **TIMELINE FINALIZED 6 MONTHS BEFORE LAUNCH - CURRENTLY MAY 1991**

Figure 7

## TYPICAL TEST SCENARIO

The different parts of a typical MAST dynamic test are illustrated in Figure 8. Each dynamic test will require a quiescent period of as yet undetermined length prior to excitation of the beam. During this time crew motion will be restricted and all but essential orbiter operations will be suspended. A preplanned, controlled excitation of the beam will be performed using the beam mounted actuators. Termination of the excitation period begins a free-decay period in which the dynamic responses of the beam will be measured using sensors at the various beam mounted instrumentation stations. These measurements will be recorded onboard and downlinked in real time. Data would be recorded continuously from some point during quiescence to the observed end of the free-decay period. These data periods may vary from times as short as 15 minutes to as much as 45 minutes. There will be an option available to initiate an active damping algorithm after some TBD number of cycles of the dynamic response. This will facilitate reduction of the time needed for the total MAST test activity.




- **TOTAL DATA PERIOD COULD BE 15 MINUTES**
- **DATA RECORDED CONTINUOUSLY FROM QUIESCENT THRU EXCITATION TO END OF FREE-DECAY PERIOD**
- **DATA RECORDED ONBOARD AND DOWNLINKED**
- **CREW AND ORBITER ACTIVITY RESTRICTED FROM PRIOR TO QUIESCENT PERIOD THRU END OF FREE DECAY**

Figure 8

## PLANNED ORBITAL TESTS FOR MAST 1

Numerous discussions with the principal investigators for MAST 1 have led to the preliminary list of planned orbital tests shown in Figure 9. This is not meant to be a definitive description of each actual test that will be run. It is only meant to illustrate the variety and number of tests that will be necessary to adequately identify the structural characteristics of the MAST beam truss. The actual number and specific process for each test must be developed during the integration and flight planning process. Definitive science test requirements that guide that process are still being developed.

| TYPE TEST | NO. OF TESTS |
|---|---|
| 1. Excitation to 25%, 50%, & 75% actuator #1 only | 3 |
| 2. Excitation to 50% single actuators #9 thru 10 | 9 |
| 3. Excitation to 25%, 50%, & 75% multiple actuators | 3 |
| 4. Parameter modifications repeat 50% multiple actuations | 4 |
| 5. Increment beam length repeat 50% multiple actuations | 2 |
| 6. Select beam length & param.mod.to match freq. of 1st bending & 2nd torsion modes, minimum coupling 50% excitation, multiple actuations | 2 |
| 7. Param.mod.for maximum coupling repeat 50% multiple actuations | 2 |
| 8. Param.mod.for 50%coupling repeat 50% multiple actuations | 2 |
| 9. 50% coupling, 75% excitation multiple actuators | 1 |
| Currently Planned Tests | 28 |

Figure 9

## MAST SENSOR/ACTUATOR LOCATIONS

The locations of the MAST remote stations are illustrated in Figure 10. Details of these remote stations have been previously discussed by Mr. Ronald Talcott in an earlier paper and will not be repeated here. There are seven remote stations, one located at the tip of the beam, five at various locations along the beam, and one on the beam baseplate. Actuators are located at the tip and at three locations along the beam. Sensors and supporting power supplies and electronics are contained in all stations.

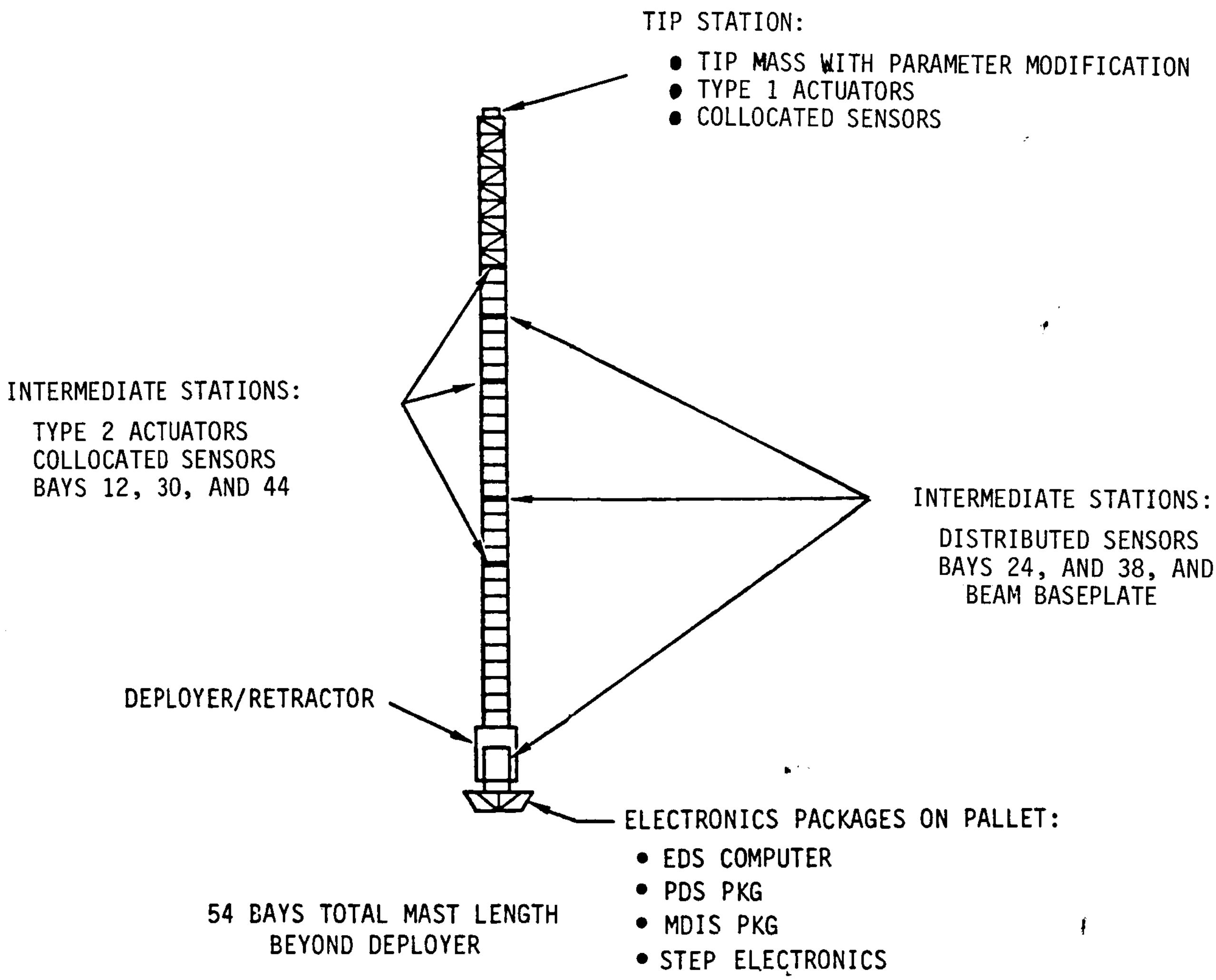
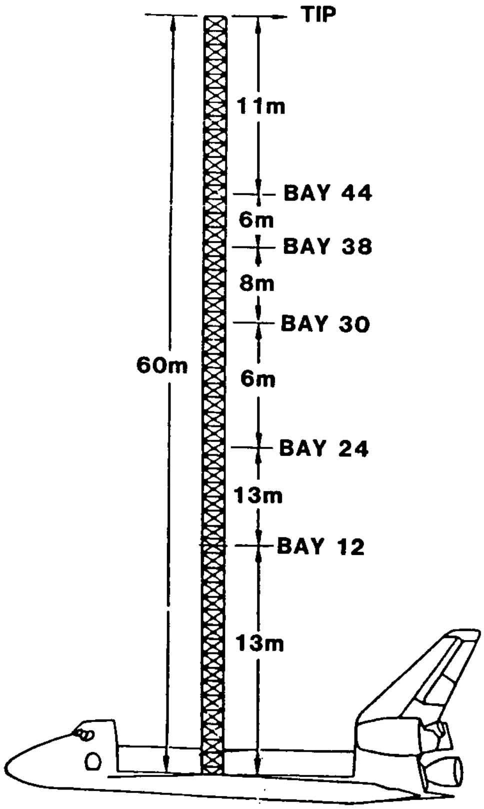



Figure 10

## SUMMARY OF MAST FLIGHT SYSTEM INSTRUMENTATION

Again, details have already been provided that describe the instrumentation system and will not be repeated here. This summary is provided to illustrate the type of sensor complement from which data will be recorded and downlinked during the orbital experiment operations.




| ACTUATOR | GYRO RATE | LINEAR ACCEL. | ANGULAR ACCEL. | STRAIN GAUGE | THERMISTOR |
|---|---|---|---|---|---|
| 4 | 3 | 3 | | 6 | 9 |
| 2 | | 3 | 1 | 6 | 3 |
| | | 2 | 1 | 6 | 3 |
| 2 | | 3 | 1 | 6 | 3 |
| | | 2 | 1 | 6 | 3 |
| 2 | | 3 | 1 | 6 | 3 |
| | 3 | 3 | | 6 | 3 |
| 10 | 6 | 19 | 5 | 42 | 27 |

Figure 11

## ORBITAL DATA PATHS

The planned data flow during the MAST 1 flight experiment is shown in Figure 12. This is not a complete depiction of every instrument or interface that will be needed during the flight. Rather it only represents the various paths that data will follow in reaching the appropriate user or repository. There are two different data rates represented: a low data rate and a high data rate. The low rate data is transferred from the modular distributed instrumentation system (MDIS) computer to the smart/flex modulator/demodulator (SFMDM). This data is a subset of the high rate data and consists primarily of housekeeping data and the appropriate safety data that must be monitored by the crew in the orbiter aft flight deck. Low rate data takes two paths from the SFMDM. It is be directed via the payload data interleaver (PDI) to the S-band downlink and eventually reaches the Huntsville operations support center (HOSC). In the HOSC, data can be stripped out and routed to appropriate display instruments for monitoring by the flight support engineering personnel. Low rate data is also passed to the data display and control unit (DDCU) where it is displayed in predefined screens that are selectable by the crew. The primary interface between the crew and the experiment is through this DDCU-SFMDM-MDIS path. The crew issues appropriate commands to operate the experiment operations and tests and monitor the feedback for appropriate responses or progress. More detail on this process can be found in the previous paper by Mr. Ronald Talcott. The high rate data is transferred directly from the MDIS computer to the high rate multiplexer (HRM). This data is essentially every data sample taken by the MDIS during the expriment process. The HRM routes data to the Ku-band downlink and to the high data rate recorder. The high data rate recorder (HDRR) records all data taken by the MDIS. The data will be periodically dumped via the HRM/Ku band and satellite links to the Goddard Space Flight Center's (GSFC) satellite network data receiving and recording facilities. Master tapes of all orbital data will be made for archives and for use by the science teams for postflight data analyses. The high rate data will also be downlinked in real time for some of the earlier beam deployments and dynamic tests. This real-time downlink will be routed via satellite links to the HOSC where some combination of HOSC instrumentation and experiment ground support equipment (GSE) will be used to provide both real time display of selected data and quick-look recordings of all downlinked data. The science team will use these quick-look recordings to do preliminary analyses to verify the beam responses as compared to preflight predictions. This process will continue overnight for each test performed to provide confirmation of readiness to proceed with the next days tests. The detailed definition of these downlink paths, data formats, and display/analysis processes is still in progress.

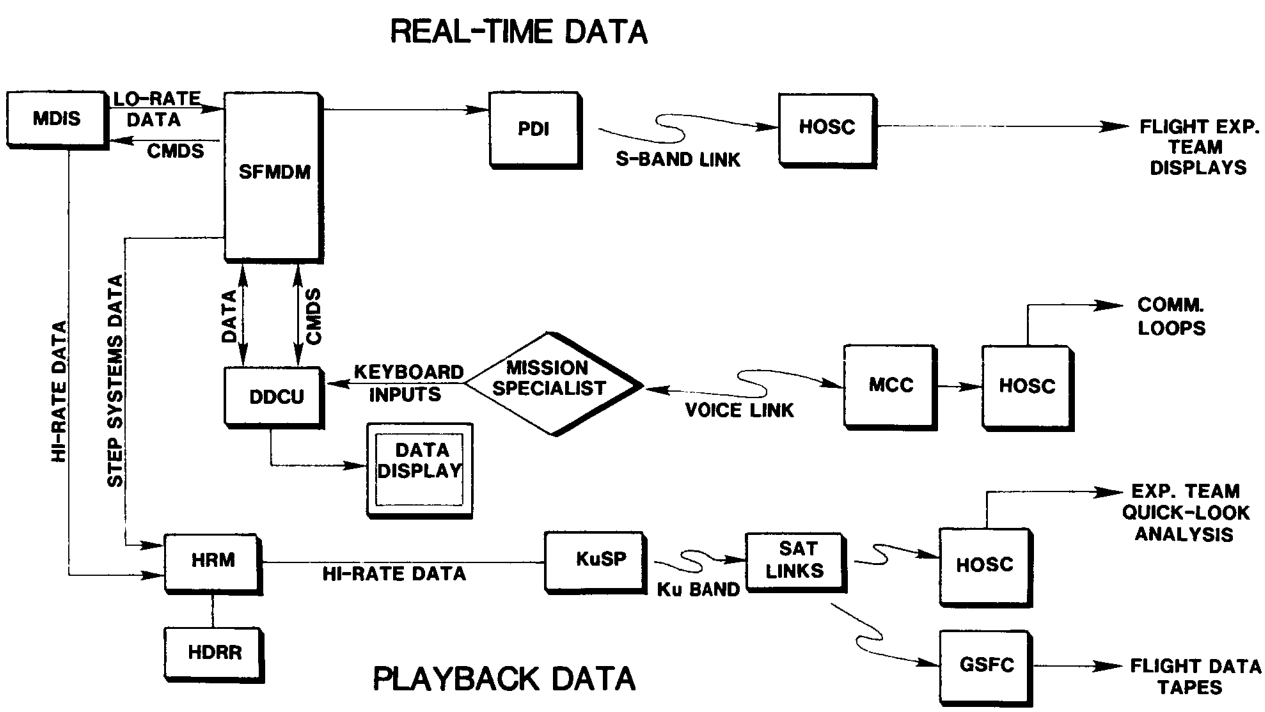

REAL-TIME DATA
MDIS
LO-RATE DATA
CMDS
SFMDM
PDI
S-BAND LINK
HOSC
FLIGHT EXP. TEAM DISPLAYS
DATA
CMDS
HI-RATE DATA
STEP SYSTEMS DATA
COMM. LOOPS
DDCU
KEYBOARD INPUTS
MISSION SPECIALIST
VOICE LINK
MCC
HOSC
DATA DISPLAY
EXP. TEAM QUICK-LOOK ANALYSIS
HRM
HI-RATE DATA
KuSP
Ku BAND
SAT LINKS
HOSC
HDRR
PLAYBACK DATA
GSFC
FLIGHT DATA TAPES

Figure 12

## PLANNED DATA ANALYSIS

Figure 13 is only a cursory description of the major thrust of analysis using data obtained during the MAST flight experiment. The specific analyses and studies cannot be envisioned at this time beyond that necessary to provide the initial structural characterization, evaluate the degree to which experiment objectives were accomplished, and prepare for the second MAST flight dedicated to controls technology.

- **PRELIMINARY ANALYSIS DURING FLIGHT USING DOWNLINKED DATA TO GUIDE THE PROGRESS OF THE TESTING AND FACILITATE ANY ADJUSTMENTS TO PARAMETERS OR LIMITS THAT MAY BE DESIRED OR NECESSARY**

- **COMPLETE POSTFLIGHT ANALYSIS OF HIGH SAMPLE RATE FLIGHT DATA USING VARIOUS STATE-OF-THE-ART SYSTEM IDENTIFICATION TECHNIQUES TO DETERMINE THE DYNAMIC RESPONSE CHARACTERISTICS OF THE FLIGHT BEAM**

- **COMPARISONS AND STUDY OF GROUND TEST RESULTS AND PREDICTED DYNAMIC RESPONSES TO THE MEASURED ORBITAL RESPONSES**

Figure 13

## SUMMARY

This paper has attempted to accomplish three purposes:

- To survey the integration process,
- To give brief insight into the planned orbital experiment process,
- To outline the data flow necessary to support the fight operations.